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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

Express Mail Label No. EV 194864924 US

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Kumar	Ramaswamy	Princeton, India

☐ *Additional inventors are being named on the _____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

Robust Mode Staggercasting

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☒ Specification *Number of Pages* 20 ☐ CD(s), Number

☐ Drawing(s) *Number of Sheets* ☐ Other (specify)

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT *(check one)*

☐ Applicant claims small entity status. See 37 CFR 1.27.

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FILING FEE AMOUNT ($) 160

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☐ Yes, the name of the U.S. Government agency and the Government contract number are: _____.

Respectfully submitted,

SIGNATURE [signature]

Date 1/28/03

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Docket Number: PU030044

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JC678 U.S. PTO
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Express Mail No. EV 194864924 US

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Complete if Known	
Application Number	
Filing Date	Herewith
First Named Inventor	Jeff Cooper, et al.
Examiner Name	N/A
Group / Art Unit	N/A
Attorney Docket No.	PU030044

METHOD OF PAYMENT (check all that apply)

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Deposit Account Number: 07-0832

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1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
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1004	750	2004	375	Reissue filing fee	
1005	160	2005	80	Provisional filing fee	160

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2. EXTRA CLAIM FEES

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1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
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1253	930	2253	465	Extension for reply within third month	
1254	1,450	2254	725	Extension for reply within fourth month	
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1401	320	2401	160	Notice of Appeal	
1402	320	2402	160	Filing a brief in support of an appeal	
1403	280	2403	140	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive – unavoidable	
1453	1,300	2453	650	Petition to revive – unintentional	
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1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17 (q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
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SUBMITTED BY

				Complete (if applicable)	
Name (Print/Type)	Ronald H. Kurdyla	Registration No. (Attorney/Agent)	26,932	Telephone	609.734.6816
Signature	[signature]			Date	1/28/03

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Robust Mode Staggercasting

Robust Mode Staggercasting is introduced as a technique to enable broadcast data to be transported over a normal and a robust channel so that the overall performance of the system is enhanced. In particular, this applies to the digital Terrestrial Transmission system proposed in the United States (ATSC A/53-B) which now includes robust modes (Annex D) to enhance the overall performance of the system. The basis of the scheme is built on the notion of staggercasting, which is the principle of sending content related to each other but staggered in time over a channel so that they can be reconstructed at the receiver. This enables the system to tolerate temporal fades.

The current ATSC standard operates over the normal channel and employs MPEG2 video compression. The choice of a compression format for the robust channel must have certain characteristics in the way it relates to MPEG2 in order to be able to exploit a more reliable transport over the robust channel. As an example, the advanced compression format chosen for this discussion is MPEG4-Part10 (also known as AVC, JVT etc.). It must be recognized that this solution extends to any system where the compression format carried over the robust mode channel has certain characteristics that will be described in detail in this paper. The current invention concerns methods to improve performance in the overall system by leveraging the characteristics of the robust channels and the specific choice of advanced compression. The goal is still to maintain backward compatibility with existing receivers within the context of the ATSC system.

The combination of the robust mode in the terrestrial ATSC system and staggercasting generalizes the concept of staggercasting to enable usage modes that can be leveraged to provide enhanced performance for a new class of receivers. It must be recognized that the robust mode stream could also be used independently of the normal channel stream. As was previously contemplated in the general principles of staggercasting, the staggered robust mode could support a stream of content compressed at a lower resolution and/or frame rate and even using an entirely different compression format. Also, it may be possible to target the robust mode to directly augment and improve the fade performance of the main channel.

Any terrestrial TV system must overcome a number of problems in transmitting signals to a receiver. For example, the United States has adopted eight-level vestigial side band (8-VSB) modulation, as proposed by the Advanced Television Systems Committee (ATSC), as its terrestrial digital television system modulation standard. The VSB system, being a single carrier modulation system, is susceptible to fading caused by multipath and signal attenuation. Any of the signal fading that is frequency selective may be corrected by equalization techniques. However this can result in degraded performance when fading occurs. If the fade is deep, wide and long enough in duration, however, the signal will be lost and the demodulator system in the TV receiver will lose synchronization.

To overcome some of the deficiencies of the 8-VSB Terrestrial standard (ATSC A/53-B), robust transmission modes (ATSC A/53, Annex D) have been proposed. These backward compatible schemes allow the creation of an additional transmission channel based on

two modes. The first mode creates a 2 or 4 VSB signal for selected frames. This mode must be used in a limited sense (less than 10% of the data rate) since the 2/4 VSB signal may cause some problems with existing receivers employing blind equalizers. The second mode creates a more robust trellis code while maintaining an 8-VSB signal. Both modes result in a tradeoff between the data rate and additional additive white Gaussian noise (AWGN) margin that is gained. It must be noted that both of these modes have flexibility in how they get used in the sense that the explicit amount of data carried over the robust channel is left to the broadcaster.

Basic Concept of "*Staggercasting*":

The concept of "staggercasting" has been proposed in earlier filed US patent applications PU010153, (Serial No.60/306,586.) PU010154, (Serial No. 60/306,565) PU010157, (Serial No. 60/307,201) and PU020126 (Serial No. 60./374,054) and is summarized here as an introduction. In-band "staggercasting" describes the process of transmitting two (or more) streams of information based on the same content, but separated in time. The streams can be identical (saving different PIDS to identify them), but to conserve channel bandwidth, one stream would be "full resolution," while the supplemental streams would be reduced resolution. If duplicate, time-staggered streams are sent, the system can transparently tolerate signal fades up to the duration of the advance of the supplemental channel. Duplicate streams would be best for data, but for video and audio, the supplemental channel could be a reduced bandwidth signal, allowing the system to degrade an image or audio stream gracefully under fading. The intent of the proposed invention is to improve the robustness of a broadcasting system in the fast fading experienced in the mobile environment or the slow fading experienced in the indoor environment.

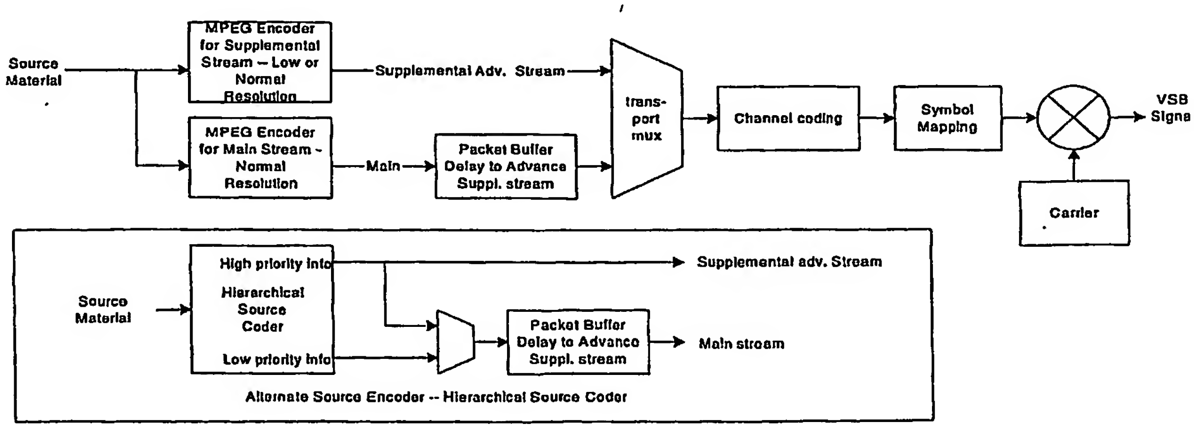

Figure 1: VSB Staggercasting Transmitter

Figure 1 illustrates the staggercasting transmitter. Source material could be encoded at the same or different resolutions or quality to form the main and supplemental channels,

or a hierarchical coding method could be used to supply the main channel with all components, but the supplemental channel with only the principal components. The main channel is delayed with respect to the supplemental channel in the transmitter.

The receiver, illustrated in Figure 2 first buffers the supplemental channel. While we explain the concept of staggercasting with the notion of "main" and "supplemental" channels for illustrative purposes, the supplemental channel may be the primary mode of operation for certain classes of systems. The notion of "main" and "supplemental" are used here purely for demonstrating the concept. Upon channel change, the receiver can begin buffering the supplemental channel, while decoding the main channel. The system will not be protected against fades until after T_{adv}, the time in the buffer, passes. The delay difference between the supplemental and main channels receiver is identified by the control stream to the receiver. The occurrence of a fading event is detected with a number of possible measures in the physical layer such as an SNR detector, bit-error rate detector, etc. When a fade occurs, the buffered supplemental data is summoned from the buffer when the main channel is identified as corrupt. This continues until either the buffer is exhausted, or the receiver recovers and the main channel is restored. Once the receiver recovers, it must stay recovered long enough to refill the supplemental buffer to prepare for another fade. The buffer delay is based on the expected fade duration -- for example between 500ms and a few seconds.

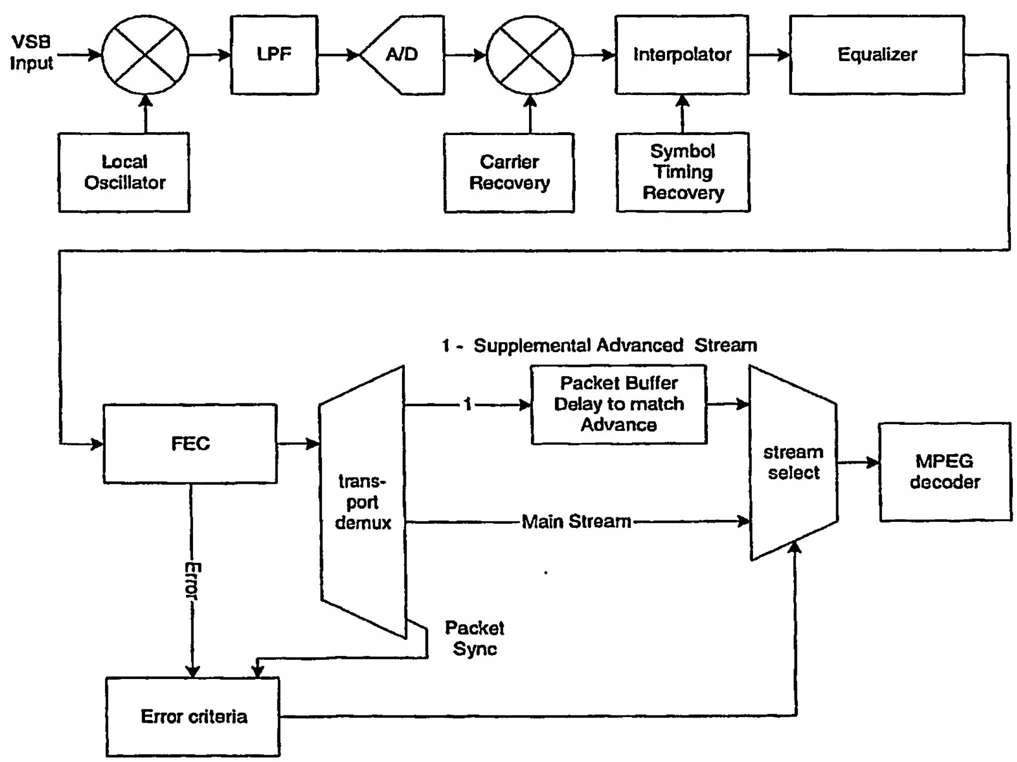

Figure 2 : VSB Staggercasting Receiver

An example fade is shown in Figure 3. The alphabetic sequence represents ordered groups of video packets. The main sequence runs from "A" to "Z", while the supplemental sequence runs from "a" to "jj". An outage in the sequence causes the loss of 6 packet groups from both the main and supplemental channels. Because the supplemental sequence is advanced by more than 6 packets, the supplemental sequence can be played from the buffer when the main sequence was lost. Until the supplemental buffer is repleted, the system is vulnerable to fades since all streams were lost in the fade. Additional delayed supplemental streams could be used to ride out multiple close succession fades, at the expense of consuming more bandwidth.

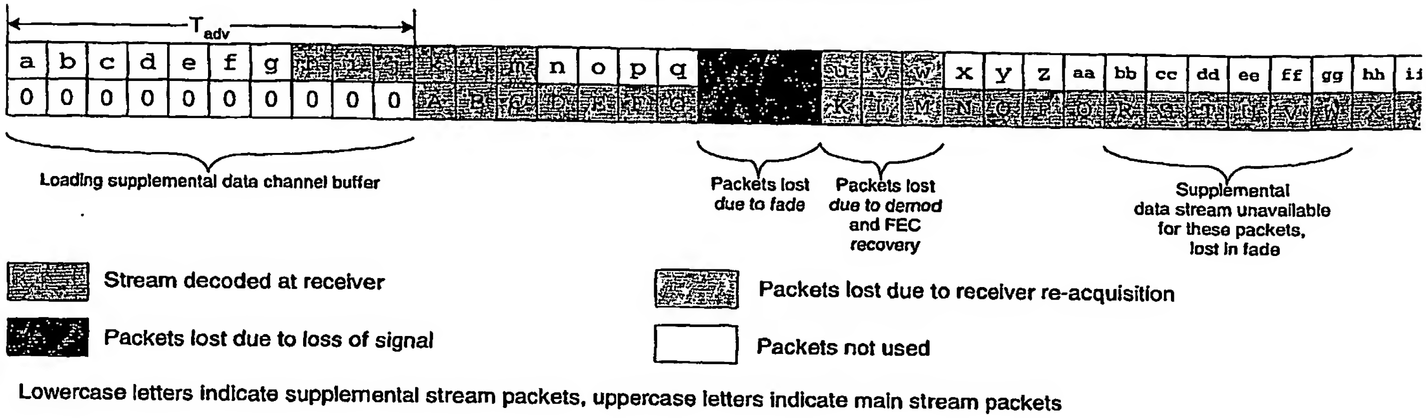

Figure 3 Illustration of staggercasting principle in packet stream

The data sent in the supplemental channel may be Forward Error/Erasure Correction (FEC) parity data. Protection against channel fades can be achieved by adding a layer of Forward Error/Erasure Correction (FEC), with the parity data computed over time periods corresponding to expected length of synchronization loss periods. Periods of data loss due to synchronization failure are considered to be packet erasures in the FEC decoder. At the encoder, an FEC encoder applies an FEC code to the data in the main channel, and transmits the parity data in the supplemental channel. The FEC codes may be applied across packets, with the length of the codes selected based on expected fade durations. At the decoder, the FEC decoder uses the data received from both the main channel and supplemental channel, with missing packets considered as erasures, to reconstruct the main channel.

Robust-Mode Staggercasting:

With the introduction of the robust modes in the ATSC standard for terrestrial broadcasting, it is now possible to staggercast in the robust mode. Consider the robust mode to be the "main" channel alluded in our description of staggercasting in the previous section and the normal mode in the ATSC system to be the "supplemental" channel. The concept of robust mode staggercasting can then be explained quite simply. A content stream is transmitted over the **robust channel**(equivalent to "main" channel in previous section) related directly to content in the **normal channel** (equivalent to "supplemental" channel in previous section) but staggered in time to exploit the

advantages of staggercasting. The current ATSC standard operates over the normal channel and employs MPEG2 video compression. The choice of a compression format for the robust channel must have certain characteristics in the way it relates to MPEG2 in order to be able to exploit a more reliable transport over the robust channel. As an example, the advanced compression format chosen for this discussion is MPEG4-Part10 (also known as AVC, JVT etc.). It must be recognized that this solution extends to any system where the compression format carried over the robust mode channel has certain characteristics that will be described in detail in this disclosure. The rest of this disclosure will describe the various methods to improve performance in the overall system by leveraging the characteristics of the robust channels and the specific choice of advanced compression. The goal is still to maintain backward compatibility with existing receivers within the context of the ATSC system.

The combination of the robust mode in the terrestrial ATSC system and staggercasting generalizes the concept of staggercasting to enable very interesting usage modes that can be leveraged to provide enhanced performance for a new class of receivers. It must be recognized that the robust mode stream could also be used independently of the normal channel stream. As was previously contemplated in the general principles of staggercasting, the staggered robust mode could support a stream of content compressed at a lower resolution and/or frame rate and even using an entirely different compression format. Also, it may be possible to target the robust mode to directly augment and improve the fade performance of the main channel. The rest of this section is organized as follows. We begin with a broad description of how robust mode staggercasting works. This is followed by a description of advanced compression formats that have certain characteristics common with the MPEG2 format (that is currently in use in the normal-mode ATSC system) which can be exploited for the robust-mode staggercasting operation. This is followed by a sample architectures for a generic encoder and decoder. This is followed by additional applications that are enabled with the robust mode. Finally, alternatives to further improvements in performance of the robust modes are discussed.

Robust Mode Staggercasting - Basics

Robust Staggercasting is done on elementary stream segments(an elementary stream segment is a Sequence, GOP,Picture or slice from a video frame or an audio packet segment). The general idea is to place a delayed version of the video/audio signal on the robust channel compared to the normal channel. The simulcast data on the robust channel can offer a range of error resiliency for the normal channel. These include periodic frame replacement, full replacement of the normal channel signal, and even enhancement for the normal channel. Data channels from the normal mode can also be simulcasted on the robust mode channel. This adds error resiliency for the data channel.

Figure 4 shows a particular example of robust staggercasting. In this example, the robust mode channel is broadcast 1 GOP time behind the normal channel. Typically, a receiver decodes and displays the normal mode signal alone. With robust staggercasting, upon the loss of the normal mode signal, the receiver can switch and display the simulcast signal from the robust mode channel. Since the robust mode is transmitted ahead of the normal mode it is available instantly to replace the loss from the normal channel. There is no

display artifact since the switch can happen immediately on the slice, frame, or sequence/GOP boundary.

In Figure 4, the grayed blocks in the normal channel represent an example of a signal loss period. Therefore, the receiver would switch to the robust channel for GOP N and GOP N+1 (the receiver could replace the entire GOPs or just the lost frames depending on the implementation; this will be discussed in more detail later). Note that this example shows the video frames, the audio packets associated with these video frames would also be delayed on the robust channel.

In the case when the robust channel is being used exclusively at the receiver and the robust signal is lost, then the normal channel can be used to replace elementary stream segments. This event can happen in receivers that use the robust channel in preference to the normal channel. This mode will be explained later.

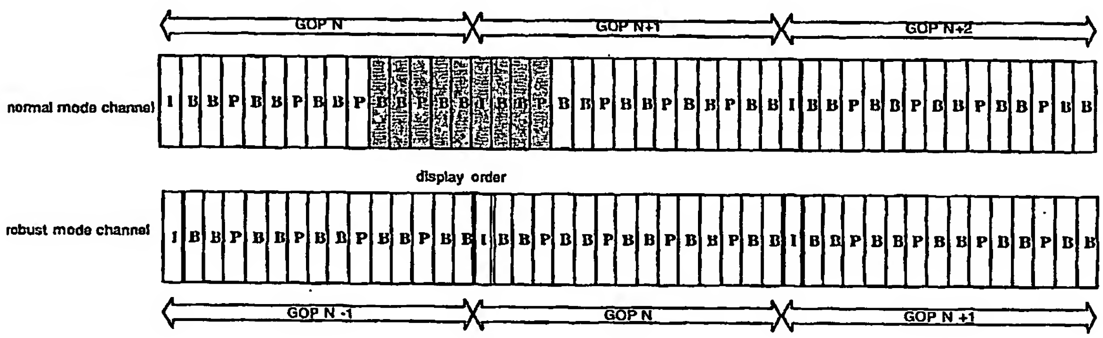

Figure 4: An Example of Robust Mode Staggercasting for Compressed Audio/Video Transmission

The delay offset between the normal channel and the robust channel can be set to any length at the transmitter. Longer delays are useful to offset large fades, however require that the receiver buffer more of the normal channel. Once the transmitter has initialized and begun broadcasting, the offset delay can not be changed. However, the amount of delay is a parameter that the transmitter can set on an encoder reset/start up. This gives individual broadcast stations the ability to tailor the robust channel for their specific broadcast environment. For example, a broadcaster in a large city with many multi-level apartment dwellings will have different fade characteristics than a rural city with single-family homes.

The maximum allowed offset will have to be specified in the ATSC robust mode spec. It is suggested that this is determined based on reasonable buffer sizes for decoder implementations, but should also allow for relatively long delays to offset large fades. It is suggested that a delay up to 5 seconds could be supported.

The minimum buffer size at the receiver is equal to delay offset buffer at the transmitter. The receiver can also support larger delay buffers at the receiver if desired. The delay created at the transmitter creates the error resiliency for fades, while the delay at the

receiver enables the use of this delayed data for a variety of error recovery modes and signal enhancements (detailed in this document).

Compression Formats Description

Two compression formats/standards are used in this system – the format used for the normal channel, and the format used for the robust channel. The two formats may be the same for both the normal and robust channel, or they may be different. The robust channel's video may be transmitted at a different bitrate, resolution, and/or frame rate as the normal channel's video. For the robust modes of the ATSC standard, backwards compatibility of the normal channel to MPEG 2 video is required, while the robust channel is free to use a more efficient compression standard, such as JVT(also known as MPEG4-Part10 or AVC). Furthermore, the relationship between the two channels must guarantee the ability to switch between the streams at the receiver within a reasonable time. This implies that some of the basic building blocks that define the compressed video streams must have a set of common elements that allow for such switching to be implemented. These common elements include clear identification of independent decoding segments, where some number of consecutive pictures may be decoded independently of previously coded pictures, as is necessary to allow channel change, clear identification of picture boundaries, and clear identification of which coded pictures are used as reference pictures in the coding of later pictures.

The MPEG 2 video compression standard includes pictures, groups of pictures (GOPs), and sequences. Pictures, GOPs and sequences are delimited in the compressed bitstream by unique start codes, e.g., a sequence is considered to be all of the data beginning with a sequence start code, up to but not including the next sequence start code. Pictures in the MPEG2 standard are either intra-coded (I pictures), coded with inter-prediction (P pictures), or coded with bi-directional prediction (B pictures). In MPEG2, I and P pictures are known as anchor frames, e.g., they are used to predict other coded pictures. In MPEG2, B pictures are not use to predict other coded pictures. In a closed GOP, all of the pictures in the GOP may be decoded without requiring reference to previously coded GOPs.

In the JVT video compression standard, each pictures is represented by one or more slices; each slice in a picture may be of a different coding type (I, P, B, SI, or SP). I slices are intra-coded. P slices are coding with inter prediction, using a single reference prediction. B slices are bi-predictively coded, using two reference predictors. Pictures containing slices of all coding types may be used as reference pictures, unless the nal_ref_idc in the Network Adaptation Layer (NAL) is set to 0, in which case they are not used as reference pictures. Each slice is placed into a NAL unit. An instantaneous decoding refresh (IDR) picture indicates that the current picture and later coded pictures can be decoded without requiring reference to previously coded GOPs.

Given these characteristics of MPEG2 and JVT, it is possible to switch between the robust-mode stream and the normal mode stream at well defined points and make a smooth seamless transition between the two channels with the same program when necessary. It must be pointed out that while MPEG2 and JVT are convenient examples

for the ATSC system, the concept of robust-mode staggercasting can be generalized to any pair of video compression techniques that share the attributes alluded to earlier.

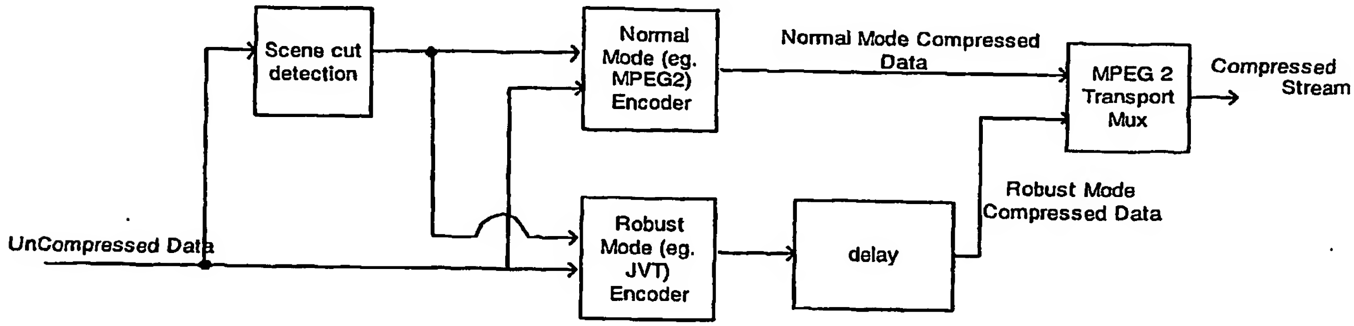

Figure 5: Robust Mode Staggercasting Encoder Implementation

Encoder and Decoder Implementations

The encoder that implements this system is shown in Figure 5. Two encoders, one each for the normal channel and the robust channel, encode the same video sequence. A scene change detector operates on the input video sequence, so that I frames are inserted at scene changes, for both encoders. In this example figure, the normal channel encoder uses MPEG2 and the robust channel encoder uses JVT. Each encoder has it own independent frame stores, for use in inter-prediction. The normal channel compressed video stream is delayed by a pre-determined amount. Then the normal channel stream and the robust channel stream are multiplexed into the same MPEG-2 transport stream.

Two possible versions of the decoder for this system are shown in Figure 6 and **Figure 7**.
Figure 6 shows a decoder that supports sequence layer switching between the normal and robust channels. The received MPEG-2 transport stream is demultiplexed, with the MPEG-2 and JVT compressed streams output. Error detection, for instance by determining that packets were missing, is also performed at the demultiplexer. A selector determines, using error detection flags as an input, which of the two channels to decode and display. A single multi-standard decoder decodes the selected channel's bitstream, which is displayed.

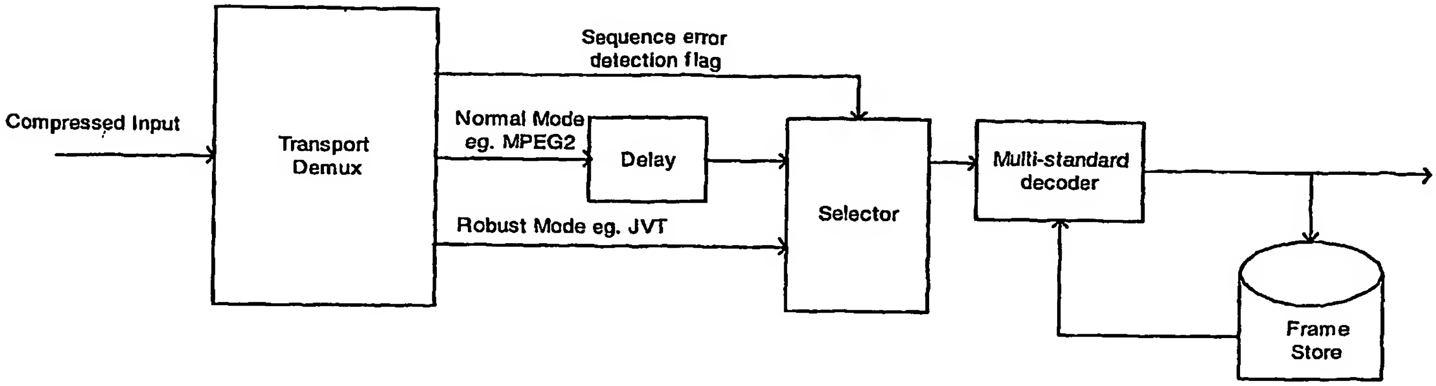

Figure 6: Robust Mode Decoder Implementation - Sequence Layer Switching

Figure 6 shows a decoder that supports picture layer switching between the normal and robust channels. The received MPEG-2 transport stream is demultiplexed, with the MPEG-2 and JVT compressed streams output. A system that supports picture layer switching between the two streams requires independent decoders for the normal and robust channels. Decoded pictures from the one format's decoder are sometimes fed back into the frame stores of the other format's frame stores. A selector determines which format's decoded pictures are sent to the display, for each picture.

It should be noted that separate decoders can be implemented with one multi-standard decoder that runs at twice the frame rate.

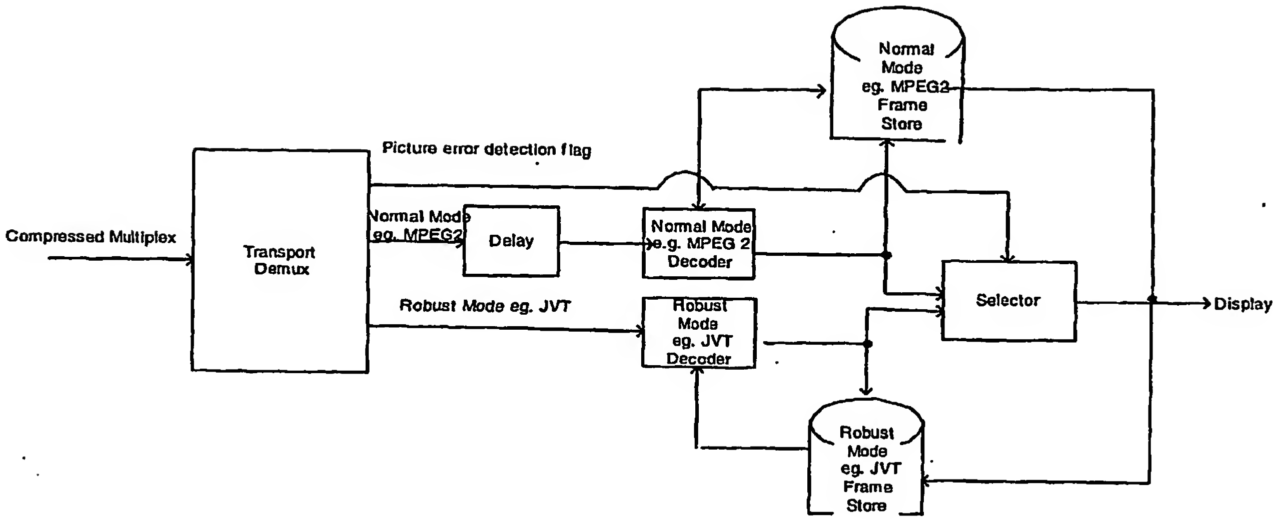

Figure 7: Robust Mode Decoder Implementation - Picture Layer Switching

<u>**Details of Switching Options in Decoder - Sequence Layer Switching**</u>

For sequence layer switching, as depicted in **Figure 6**, a decision is made for each sequence whether the robust channel or the normal channel compressed data will be decoded and displayed. A single multi-standard decoder and associated reference frame storage may be used. For sequence layer switching, the encoder must insert re-entry points (I pictures for MPEG-2, IDRs for JVT) corresponding to the same pictures. Other pictures in the two formats may have corresponding picture types, but are not required to.

A sample sequence of coded pictures for an MPEG-2 normal channel is shown below. Transmission order rather than display order is used in this illustration. In this example, a

Example:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MPEG:	I	B	B	P	B	B	P	B	B	P	B	B	P	B	B

With the addition of the staggercasting delay, the robust channel data is transmitted later in time. For example, the delay could be equal to the period for re-entry points, as depicted below:

NORMAL

Seq :	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
MPEG :	I	B	B	P	B	B	P	B	B	P	B	B	P	B	B	I	B	B	P	B	B	P	B	B	P	B	B	P
error:							x				x																	
ROBUST																												
Seq:																0	1	2	3	4	5	6	7	8	9	10	11	12
JVT:																I	B	B	P	B	B	P	B	B	P	B	B	P
error:																												

In the example above, the *n*-th I frame of the Robust channel is delayed to arrive when the (n+1)st frame in the normal channel arrives at the receiver. At the transport demux, transmission error detection is performed on the received normal and robust channel sequences, for example by recognizing gaps in the transport packet continuity counters. If all of the pictures in a sequence, i.e., pictures 0-14, were received without error for the robust channel, but with errors for the normal channel, the selector would choose to decode and display the robust channel. For example, as illustrated above, transmission errors occurred in normal channel for pictures 6 and 10, so the robust channel data is decoded and displayed for the sequence containing pictures 0-14. Conversely, if pictures 0-14 were received without error for the normal channel, but with errors for the robust channel, the selector would choose to decode and display the normal channel. In the case where all picture in the sequence were received without errors for both the normal channel and the robust channel, additional criteria are used to select which channel's data to decode and display. Several selection methods are described later. Similarly, if transmission errors were present for the sequence for both the normal channel and the robust channel, additional criteria are used to select which channel's data to decode and display, and in addition, error concealment techniques should be utilized.

<u>Details of Switching Options in Decoder - Picture Layer Switching</u>

Picture layer switching allows a more fine grain switching between the normal and robust channels, as compared to sequence layer switching. This is advantageous when the robust channel video stream is compressed with a reduced resolution, frame rate, or video quality as compared to the normal channel stream, or when the error conditions are such that transmission errors tend to occur even in the robust stream. A decoder supporting picture level switching must include two independent video decoders and associate reference frame storage, one each for the normal channel format and for the robust channel format.

Picture layer switching where the robust channel video is compressed with a lower quality than the normal channel will now be described in detail. If a normal channel picture is received without transmission error, it is always selected for display, and if it is a reference picture (I or P picture for MPEG-2), for storage in the normal format decoder reference frame store. The robust channel data is received and decoded and stored, but is not displayed. However, if transmission errors occurred for another normal channel picture and the same robust channel picture is received without errors, the decoded robust

channel picture is selected for display, and if it corresponds to a reference picture in the normal channel (I or P picture for MPEG-2), the decoded robust channel picture is stored in the normal channel reference frame store. While replacing the unavailable normal picture with a substitute picture from the robust channel which is of lower quality will reduce the video quality somewhat for the rest of the sequence, the subjective is likely to be significantly higher than what could be achieved using error concealment techniques for the normal channel data only.

For picture layer switching at the decoder, with support for two independent video decoders, there is no longer a requirement at the encoder that re-entry points be placed at identical pictures. However, an encoder that wishes to support both types of decoders would still have to enforce that restriction.

An example of picture layer switching is illustrated below. Transmission errors occur in the normal channel for pictures 6 and 10, while all pictures in the sequence containing pictures 0-14 for the robust channel are received without error. (Transmission order rather than display order is used in this illustration.) All compressed data from both channels is decoded, using the appropriate decoder, with the normal channel delayed sufficiently so that the robust channel data corresponding to the same pictures is available. Pictures 0-5 are received without error for the normal channel, so they are selected for decoding, and reference pictures 0 and 3 are stored in the reference frame store. Picture 6 has an error for the normal channel, but is without error in the robust channel. So the robust channel's picture 6 is displayed and stored in the normal channel's reference frame store. Pictures 7, 8, and 9 are decoded and displayed using normal channel data, but making use of the robust channel's picture 6 that was stored in the normal channel frame store, instead of the absent normal channel picture 6. Picture 10 also was subject to a transmission error for the normal channel, so the robust channel's picture 10 was displayed instead. Because picture 10 is a B-picture in the normal channel, it does not need to be stored in the reference frame store.

```
NORMAL
       0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
MPEG :I  B  B  P  B  B  P  B  B  P  B  B  P  B  B  I  B  B  P  B  B  P  B  B  P  B  B  P
error:                  x           x

ROBUST
                                                   0  1  2  3  4  5  6  7  8  9 10 11 12
JVT:                                               I  B  B  P  B  B  P  B  B  P  B  B  P
error:

DISPLAY
                                                   0  1  2  3  4  5  6  7  8  9 10 11 12
                                                   M  M  M  M  M  M  J  M  M  M  J  M  M
```

Additional Features of Robust Mode Staggercasting:

a) Smoothing while Switching:

When the robust channel video is compressed with a lower resolution or quality than the normal channel video, abrupt switching between the normal channel video and the robust channel video may be subjectively objectionable to a viewer. Smoothing of the transition can reduce the subjective impact. This is more of an issue for sequence layer switching than for picture layer switching, as changing of resolution for a single picture is much

less noticeable by a viewer. For the last few pictures of the normal channel video that precede a switch to robust channel video, a filter which gradually reduces the resolution for each picture, until it closely matches the resolution of the robust channel video, may be applied to the decoded picture before display. Similarly, for the first few pictures after a switch to the normal channel from the robust channel, a filter is applied that reduces the resolution less and less for each subsequent picture until it is disabled and normal channel pictures are displayed without filtering.

b) Implementation Details of Variable Delay for Robust Mode Staggercasting :

The staggercasting offset amount and other information is transmitted in the ATSC PMT table and the PSIP-VCT table. Since either or both of these tables can be implemented in a ATSC system, both are supported here with syntax and semantics.

Robust channels that are not simulcast versions of normal channel data are indicated with existing PAT/PMT and PSIP-VCT syntax and semantics. The additional syntax listed below is only with respect to simulcast versions of data on the robust mode channel.

Number_of Robust_simulcast_channels	up to 256 channels supported	8 bit uint
For (i=0; i<number_of_robust_simulcast_channels;i++){		
Robust_Mode_PID	Identifies this channel in the TS	16 bit uint
Simulcast_data_type	0 = video 1 = audio 2 = data	2 bit uint
If(data_type = 0){		
Robust_Mode_video_compression_format	0 = ATSC MPEG2 MP@HL 1 = JVT MP@level all others reserved for future use	6 bit uint
Robust_Mode_video_frame_rate	Frame rate in frames per second	7 bit uint
Robust_Mode_video_frame_interlaced	If 0 then progressive; else interlaced	1 bit uint
Robust_Mode_video_frame_horz	Horizontal frame resolution	16 bit uint
Robust_Mode_video_frame_vert	Vertical frame resolution	16 bit uint
Robust_Mode_video_frame_bitrate	Video elementary stream bit rate in bps	32 bit uint
Else		
Robust_Mode_audio_compression_format	0 ATSC AC-3 1 MP3pro all others reserved	6 bit uint
Robust_Mode_audio_bitrate	Audio elementary bit rate in bps	24 bit uint
Robust_Mode_audio_sample_rate	Audio sample rate in Ksamples per sec	8 bit uint
Robust_Mode_audio_mode	0 5.1 channels 1 2 channel others	8 bit uint
}		
Normal_mode_simulcast_PID	PID of the normal channel which this robust mode channel duplicates.	16 bit uint
Robust_to_Normal_delay_offset	A 32 bit value in 90 KHZ clock cycles indicating the delay from robust channel to the normal channel	32 bit uint
Robust_Mode_High_Quality	IF 0 THEN the receiver should use the normal channel if available ELSE the broadcaster recommends use of the robust channel instead of the normal channel	1 bit uint
} // end for loop robust chanels		

Table 1: Support for Robust Mode Staggercasting in ATSC PMT and PSIP-VCT

In table1 the number_of_robust_simulcast_channels indicates how many different elementary streams exist that are used to represent a simulcasted version of the normal mode. A syntax loop is included for each elementary stream. Video, audio, and data can be simulcast on this channel.

Some descriptive information is given for each channel that indicates to the receiver which version of the content it can use. For example, in a mobile device the receiver will look for video content in a smaller video resolution. The average bit rate is given which helps receivers with PVR capability plan storage usage.

The normal_mode_simulcast_PID identifies the elementary stream in the normal channel that this particular robust_mode_PID represents.

The robust_mode_high_quality bit indicates to the receiver if this particular simulcast version is preferred over the normal channel. That is, in some cases the broadcaster may be providing a very high quality signal on the robust channel that is equivalent or better than the normal channel.

For the VCT, these additional fields are placed in the descriptors field. It is also recommended that the "service type" table in the VCT be amended to include a "robust" and a "robust simulcast" service type. However, these are not strictly necessary with the addition of the above specified new table.

The PTS and PCR will be used as per a traditional ATSC transport stream. In addition, the PTS will indicate to the receiver which video frames of the robust channel correspond to the same display periods of the normal channel. Referring to figure 1, the PTS of the Intra frame of normal mode GOP N is equal to the PTS of the Intra Frame of robust channel GOP N. That is, when GOP N needs to be replaced due to loss of the normal channel, the receiver can look at the robust mode PTS fields to determine which frames line up. Again, this works whether on a frame or sequence level of offset or replacement.

The normal mode channel and the robust mode channel carry PCR fields that are inserted by the transmitter multiplexer (typically). Therefore, either channel can be used to recover the PCR driven clock at the receiver. In fact both can be used simultaneously to drive the PLL at the receiver since the PCRs are inserted in the transport stream at one location at the transmitter.

c) Multiple Delays with Multi-Resolution

As has been discussed earlier, the robust channel could carry program information which is the same as the information in the normal channel. There are several ways in which this information can be carried over the robust channel:

(i) Scalable information staggered in time in such a manner that it would be possible to reconstruct better estimates of the normal channel with longer delays. This implies that the base layer for the scalable codec be staggered

in time but be sent first. Following this, it would be possible to carry the enhancement layers.

(ii) Multiple resolutions that have been individually compressed and staggered in time with respect to the normal channel and with respect to each other. Since the resolutions can span for QCIF up to HD resolutions, it is clear that the lower resolution content can be carried for a very small fraction of the highest resolution signal. Additionally, if the exact staggered pattern in which the multiple resolution signals are carried is communicated to a receiver, it will be possible for receivers with varying resolution displays and computing capabilities to only process the data corresponding to the resolution of interest. This could have very important implications for portable battery operated devices which may choose to process a signal of lower resolution as a means to conserve power when necessary.

d) Support for Fast Channel Change

Channel change time is a strict design constraint for broadcast networks. When the receiver user switches channels it should take no longer than 0.5 to 1 second typically to display the first image on the newly tuned channel. That is, to achieve a good response time for the user experience.

Robust Mode staggercasting does not reduce the channel change time compared to a single normal broadcast channel. This is achieved by using the robust channel for the first displayed signal until the normal channel PTS is equal to the PCR indicating the normal channel is available. Referring again to Figure 4, in this case the delay period is one GOP time. At the instant of the channel change the receiver decodes and displays GOP N-1 from the robust channel. During this time the normal channel fills its buffer for the staggercast delay period. In this example after the first GOP time the normal channel is available and then the receiver switches to decode and display normal channel GOP N. As can be seen, no added delay is added to the channel change time INDEPENDENT of the staggercasting delay period.

e) User Switching Modes:

When both the normal and robust mode are being transmitted, it is important to provide within a user guide or user interface the ability to choose the mode of reception that is acceptable to them for viewing. Alternatively, the user should also have the choice of allowing the system to make the determination automatically based on metrics. This information is also useful since a variety of user display devices may be supported with differing capabilities.

Included in the PSIP-VCT and PMT new information above is the flag **Robust_Mode_High_Quality.** This flag indicates to the receiver that the robust simulcast channel is being transmitted at high quality and can be used in full replacement of the normal channel. By using advanced compression techniques such as JVT it is possible that very high quality HD signals can be sent with low bit rates and due to the improved robust channel transmission characteristics should be used

exclusively. When operating in this mode, the normal mode channel can be used as a backup if the robust channel happens to lose signal.

This **Robust_Mode_High_Quality** flag will be used in tandem with user interface controls built into new HDTV receivers. The following controls are suggested for new receivers:

a) an EPG option to display the simulcast channels and their associated information such as "high quality" flag and video and audio frame rate flags. This would allow the user to surf the guide and decide which channel version to choose of 2 or more simulcast options

b) through custom settings in the user interface,the EPG and channel change directory could be directed to
   a. display all simulcast channels
   b. display only simulcast channels with **Robust_Mode_High_Quality = 1**
   c. do not display any simulcast channels

in these cases the word display indicates for channel change directories which channel (normal or robust) to tune to during channel up down surfing.

f) Hysteresis Concepts for Rapid Fade Reception:

When the robust channel is being used frequently to replace lost normal channel frames and GOPs, the visual effect of switching can be disturbing to the user if the robust channel resolution, frame rate or quality are vastly different than the normal channel. For these cases, the receiver should include hysterisis in the switching algorithm. For example, the receiver should have pre-defined thresholds for normal to robust switching rates. If this rate is exceeded then the receiver will wait for the defined threshold delay before switching again.

An example is in the case when the HD normal channel is fading on and off frequently, but the robust simulcast channel is SD instead of HD resolution. In this case, the receiver has to upscale the robust SD resolution to HD for the display and this generates a poorer video signal. Also, the switching is noticeable to a casual user. If the signal is switched more than 2 times per minute then the receiver should decide to keep the receiver in robust mode for at least 1 minute for every switch. This is just one example of hysterisis and how it could be used in the receiver. Empirical data will have to be used to derive good thresholds for hysterisis.

g) Multiple Description Coding

The robust channel can also be used as an enhancement channel for the normal channel. In areas where normal channel reception is good (or as receivers improve VSB fade resistant capability), it is more beneficial to use the robust channel for normal channel enhancement in addition to error resilience.

Increasing the normal channel temporal frame rate is proposed. For example, today the maximum ATSC frame rate and vertical resolution is 30 fps at 1080 interlaced. By using

the robust channel with an additional 30fps 1080 interlaced signal, a combined 1080 progressive 60 fps signal can be created.

Figure 8 shows the interlaced lines of a 1080 p signal. Traditionally, an ATSC normal channel can only support the green and dashed blue line to form a 1080i video sequence. However, by placing the dashed red and dashed-dotted pink lines into a second 1080i video sequence for the robust channel, a receiver decoding both normal and robust channels can combine the received signal into a 1080p signal. This will offer very high end HDTVs with a new feature with unparalleled visual clarity(especially for high action content).

This mode can also be used to increase the resolution of other normal modes such as 480i or any other interlaced format. In addition, the progressive formats can be split between the normal channel and the robust channel. For example 720p 60 fps could send the odd 720p frames on the normal channel and the even 720p frames on the robust channel.

In the case of loss on either the normal channel or the robust channel, a traditional de-interlacer could be used at the receiver. (traditional de-interlacers filter existing pixels to fill in the missing fields). Therefore, the display can be a true 1080p 60 fps at all times.

Typically in this mode the broadcaster would use a very high quality encoding to remove any artifacts caused by different encoders running on opposite fields. In this case the robust channel and normal channel are equal in quality. Therefore, the broadcaster could set the robust_mode_high_quality flag to indicate to the receiver to use the robust channel by default.

Figure 9 shows the block diagram of an encoder that supports the notion of dual interlace for improved resolution.
Figure 10 shows the block diagram for such a receiver with two decoders necessary and the additional de-interlacer block that combines the channels display outputs.

Interlacer

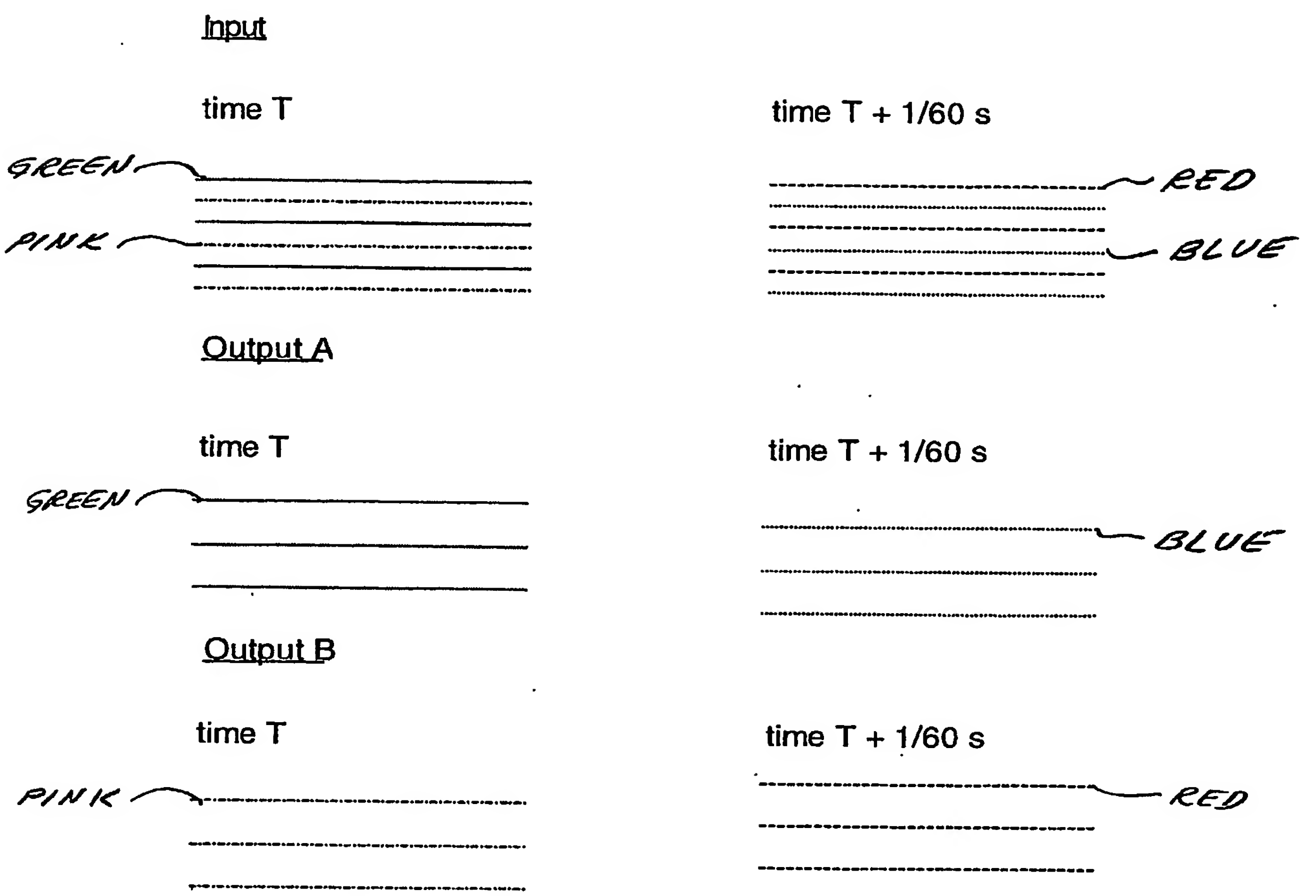

Figure 8: Progressive Frame Composition in Robust Mode Staggercasting

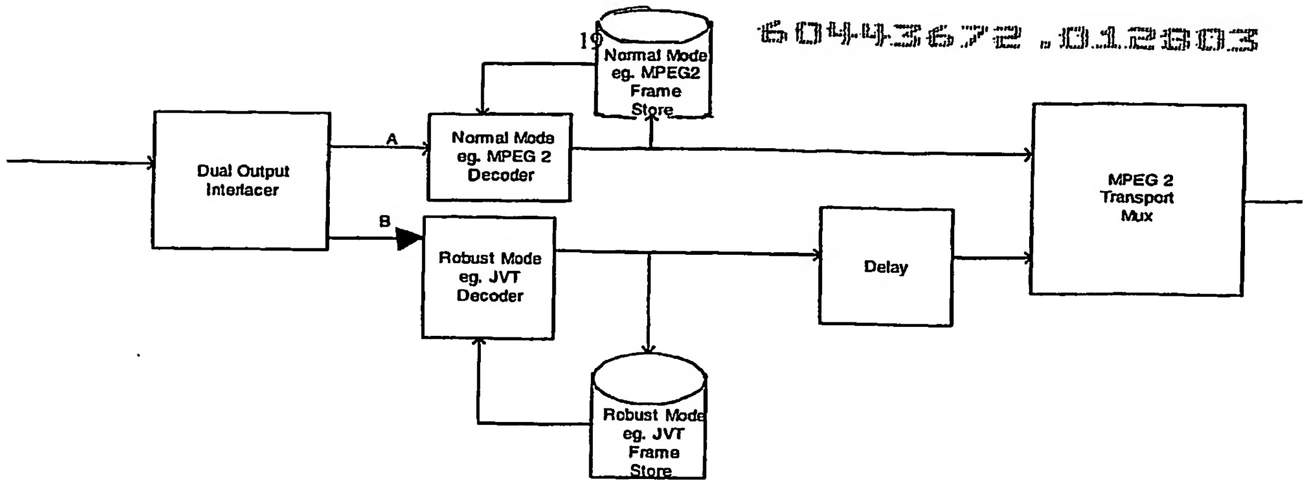

Figure 9: Encoder with Dual Interlace Support

h) Storage of Robust Mode Staggercasting Content

As the cost of storage continues to drop, digital personal video recorders (PVR) functionality will become pervasive in most digital receivers. With the availability of normal and robust mode staggercasted signals, there are several choices that can be made

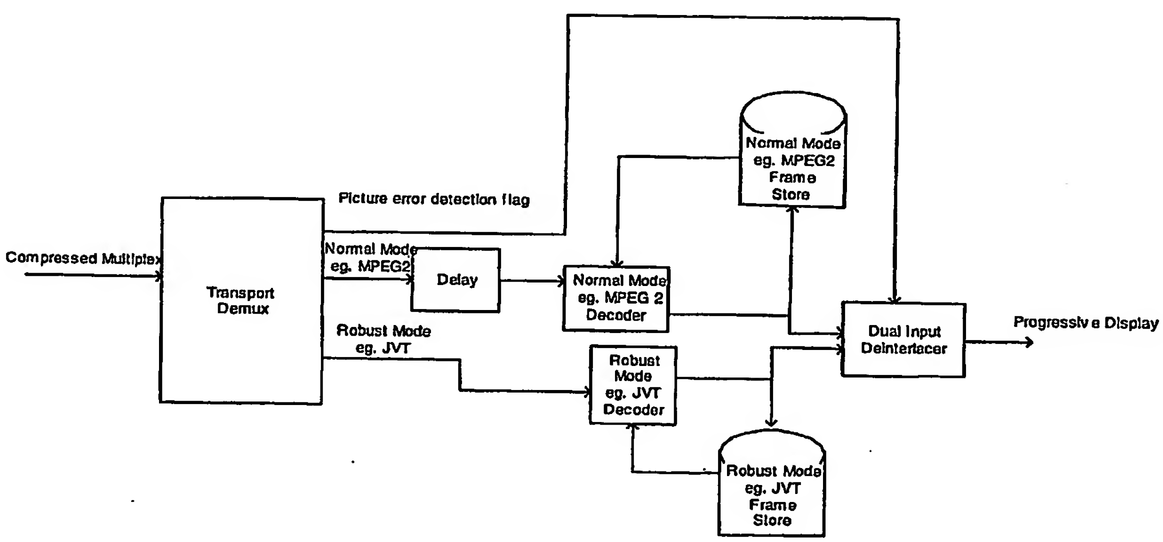

Figure 10: Decoder with Dual Interlace Support

either manually by the user or automatically by the system to choose the recording format. Some options include:

i) Record the best received combination sequence (of the normal and robust channels)

ii) Record the channel of lower resolution (if available) to conserve disc capacity(with fill-ins from the higher resolution channel if the lower resolution signal was lost) and possibly do this intelligently and automatically when a certain disc capacity level is detected.

iii) Allow the user the freedom of choice (much like the LP and SP in video cassette recorders)

i) Audio Support for Robust Mode Staggercasting:

It is important to consider support for compressed audio even in the absence of a main channel signal. We propose staggercasted audio (possibly compressed in a different format than the normal channel) in the robust mode channel as a means to allow for a graceful degradation of the reception. Also, all scalable, multi resolution and multiple description variants of audio can be supported for a very small increase in the overall rate in the robust mode channel.